ARRIVET

DESIGN AND OPTIMIZATION OF COOLING CHANNELS IN HOT STAMPING DIES APPLYING ADDITIVE MANUFACTURING DESING CONCEPTS

Gorka Goikoetxea Urkiaga[1], Eneko Iriondo Iturregi[2] and Hodei Lete Irazabal[3]
Email: gorka@zulaibar.org[1], eneko.iriondo@zulaibar.net[2], hodeilete@laudioalde.eus[3]
Arratiako Zulaibar Lanbide Ikastegia, Basque Country, Spain [1,2]
Laudioalde Lanbide Eskola, Basque Country, Spain[3]

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ABSTRACT:
The stamping process is a process that represents a key manufacturing process in automotive industry. With the implementation of the stamping process, mechanical elements obtain mechanical resistance, in addition to a very low ratio in quantity/cost.
Within the design premises that govern the automotive industry, it is worth highlighting the requirement for mechanical resistance, passenger safety and the lightness of materials.
All of this contributes to the current use of alloyed materials with high mechanical resistance. These materials, in addition to keeping the mechanical requirements of the different components subjected to load, must satisfy the geometric requirements established by the designers. In the last few years, the use of the Ultra High Strength steels has grown in automotive industry. This type of alloyed steels contributes into car safety and clean mobility.
Given the mechanical nature of these ultra-high-strength alloys, they require the use of hot stamping. This makes the deformability of the different steels easier and allows that, using a conventional stamping method, would not be able to deform according to the geometric requirements of the different mechanical components.

Keywords: hot stamping dies; colling system optimization; additive manufacturing

1. INTRODUCTION

The demand of new processes to produce high strength parts, under appropriate cost and productivity, has grown with weight reduction and crash safety improvements in automobile design (Mori et al., 2017). The development of new products in the automotive sector, opens the possibility of including new materials in these areas so that they can satisfy mechanical demands. Given this development, materials based on high-strength alloyed steel HSS and ultra-high strength can be cited. These steels, in addition to meeting mechanical requirements, must comply with geometric requirements to satisfy designer requirements. Moreover, due to the current trend towards lightweighting in the automotive industry, component lightweighting has become a fundamental objective in engineer design requirements. This is due to the significant savings in the carbon footprint that automobiles leave throughout their lifecycle. The demand volume for these materials and the hot stamping process are growing and gaining greater presence in automobile construction.

As an illustrative example, we can analyse the presence of Ultra High Strength Steel (UHSS) in a specific model, namely the Volvo XC90. In Fig 1.1, it can be observed that in 2007, the percentage of UHSS steel reached 7% (Casajús, 2018).

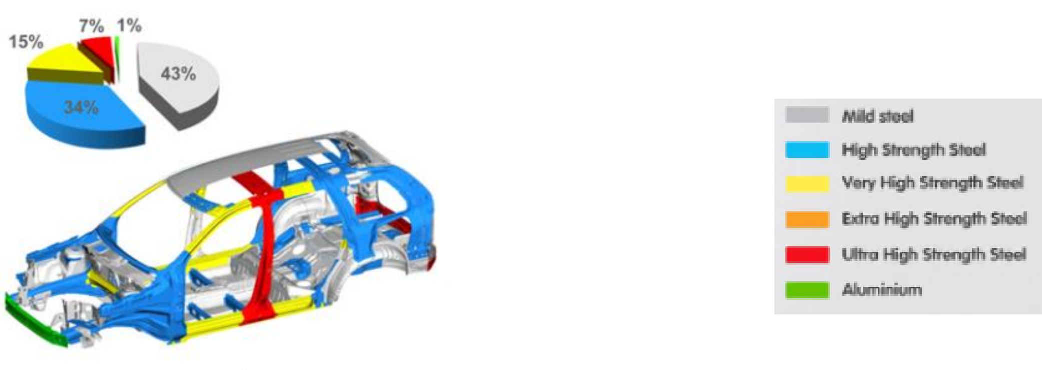

Fig 1.1 UHSS steel and HSS in Volvo XC90 structure 2007 (Casajús, 2018).

In figure 1.2. The percentage of these steels reaches 40%, in the same car model in 2015 (Casajús, 2018).

Fig 1.2 UHSS steel and HSS in Volvo XC90 structure 2007 (Casajús, 2018).

It is a process which entails heating the material until it becomes malleable. It is subsequently subjected to a formation and rapid cooling process to produce a transformed and hardened material. This quick and effective process requires fewer steps than the traditional stamping process and achieves lighter and more resistant products (Loire Gestamp, n.d.).

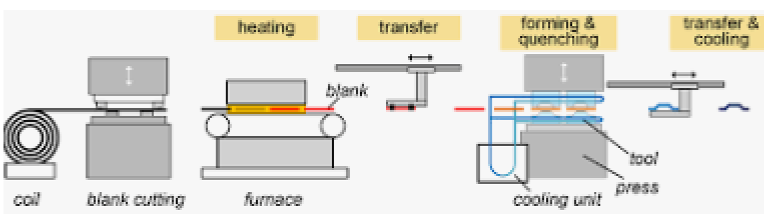

Fig. 1.3 Thermo-mechanical interactions in hot stamping (Loire Gestamp, n.d.).

With the aim of reducing weight, improving safety, and increasing the impact resistance of vehicles, the industry has given great importance to the use of boron steel in recent years. Boron steels are a type of steel which enables the material to obtain a fully martensitic structure after its quenching with water. The high carbon content of this type of steel allows it to achieve great strength, lightness, and characteristics propitious to welding.

The temperature of these steel precipitations must reach 920ºC to dissolve the boron carbides in order to obtain a good level of hardenability. Boron steel alloys have a resistance of approximately 500 MPa and reach 2,000 MPa after tempering (Koniker, n.d.).

In the hot stamping process, the material cooling process becomes crucially important, as in this stage, thanks to the temperatures reached in the process, exceeding the austenification temperature, both the internal metallographic structure of the material and its mechanical properties are modified.

In this area, it can be mentioned the development and optimization of internal cooling channels in stamping tools. The cooling process is the most important stage for the final cost of mechanical components obtained in this manufacturing process. Reducing the cycle time of production lines integrated with hot forming processes is crucial.

All of this is conditioned by the drilling manufacturing techniques used to obtain the cooling systems. The main limitation is the dimension of diameter and length of the drilling tools. In many cases, this limitation implies not being able to optimize the cooling system entirely, and the cooling process of the sheet is not entirely homogeneous, resulting in hot spots where optimal cooling cannot be ensured.

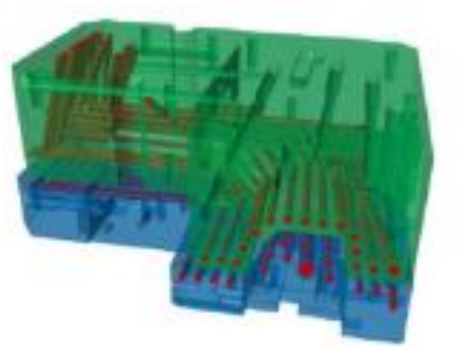

Fig 1.4. Hot Stamping Cooling System (Zakaria et al., 2018).

Automotive industry faces new challenges every day, new design trends and technological deployments from research push companies to develop new models and facelifts in short term, requiring new tools or tool reshaping. Concerning the current world economic scenario, decreasing time for tooling up becomes as important as decreasing time-to-market. Such scenario opens up the horizons for new manufacturing approaches like additive manufacturing, in this case, applied for tooling up a stamping process on the automotive industry for the production of body panels (Leal et al., 2017).

Thanks to the versatility offered by additive manufacturing, it is possible to optimize the cooling channels to the maximum. This process breaks with the barriers of traditional chip removal manufacturing, allowing the adaptive design of channels to the contour of the sheet and the change of the channel section geometry. This maximizes heat transfer between the cooling liquid and the sheet.

2. METHODS

In this paper, the optimization of the cooling system of a hot stamping die will be analysed, using a CAE finite element analysis, together with the redesign of the blocks that constitute the stamping die. To do this, we will analyse and optimize the cooling of a hot stamping die used in the production of a B pillar.

The analysed model is based on a design in the CATIA software. The NX design software will be used as CAD/CAE study software. We will begin by simplifying the block, to later be able to define an optimal channel geometry, making the adaptive cooling channels on an isoperimetric surface of the sheet metal surface.

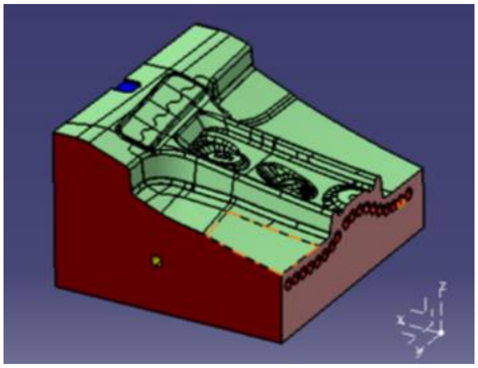

Fig 1.5. Pilar B Stamp Die Block analysis case in CATIA

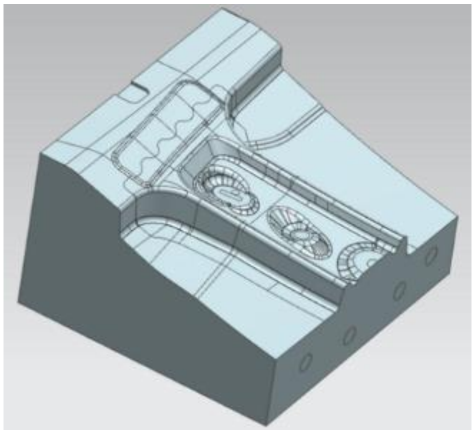

Fig 1.6 Simplified die block design NX

The analysis parameters that will be used are these Fig 1.8.

Hot Stamping process parameters	
Analysis type	Transient thermal analysis
Die Bloc Material	CR7V-I
Sheet Metal Material	22MnB5
Simulation cycle	20 sec
Die 0 Temperature	25ºC
Sheet Metal 0 Temperature	800ºC
Refrigeration Liquid	Water
Water 0 Temperature	20ºC
Water Flow	6.6 Kg/seg
Water Pressure	8 bar
Heat Transfer	stamping block and environment 0 mW/mm2K
Conduction heat transfer between sheet metal and die block	2500W/m2ºC

Convection heat transfer between die block and cooling water	0.3mW/mm2K

Fig 1.7 Analysis parameters

In the design of the cooling channels, in addition to the geometry of the channel section, channels adaptive to the geometry of the sheet metal have been made.

As a starting point we will start from the analysis of the optimal section of the channel using a CAE analysis of the different basic geometries. To do this, we must first define the finite elements for the CAE analysis.

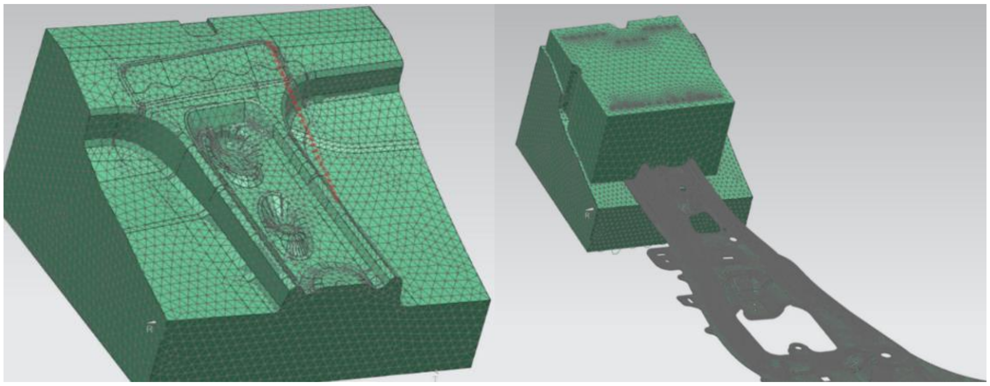

Fig 1.8 Finite Elements definition CAE software

CAE Finite Elements Definition	
Stamp die Block Mesh	3D tetrahedral (size 10)
Sheet Metal Mesh	2D elements (size 5)
Water Mesh	1D elements (cooling hole section)

Fig 1.9 Finite elements type

For the optimization of the channel section, simple geometries have been defined with the condition that the area of the section is equal. To do this, a control point has been defined on the sheet, and the influence of the geometry on heat exchange has been analysed.

Finally, the adaptive channels have been defined on the isoperimetric surface with an offset of 10mm. Being able to adapt the channels to the geometry of the sheet metal.

3. RESULTS

3.1 Section geometry analysis

The optimal section for the design of the cooling channel has been defined. For this, a circular, square, oval, hexagonal, and drop-shaped section has been used. Strictly complying with the requirement that the section area is the same Fig 1.11.

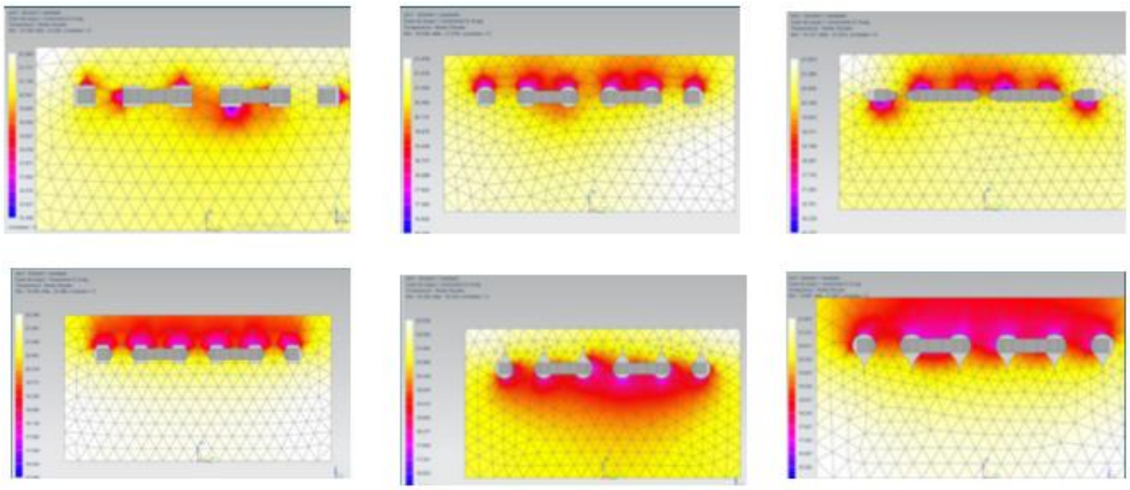

Fig 1.10 CAE analysis of section geometries

The results obtained in the different sections analyses Fig 1.11:

Type of section	Temperature control node ºC
Circular	20.8155
Square	21.698
Oval	20.623
Hexagonal	20.179
Drop shape	17.2324

Fig 1.11 Temperature in sheet metal control node

In this analysis the heat dissipated by the drop-shaped section is the most effective. Furthermore, it can be observed that the inverted drop shape is the one that dissipates the most heat and therefore obtains the lowest sheet metal temperature in the control mode.

If we analyse the data obtained, we can see that exist a difference between the two geometries that obtained the lowest and highest temperatures. We can affirm that the difference obtained is 17.06% more optimal comparing the circular geometry and the drop shape.

Once the optimal geometry for the cooling channel section has been defined, the channels have been designed to adapt to the isoparametric surface of the sheet with an-offset of 10mm.

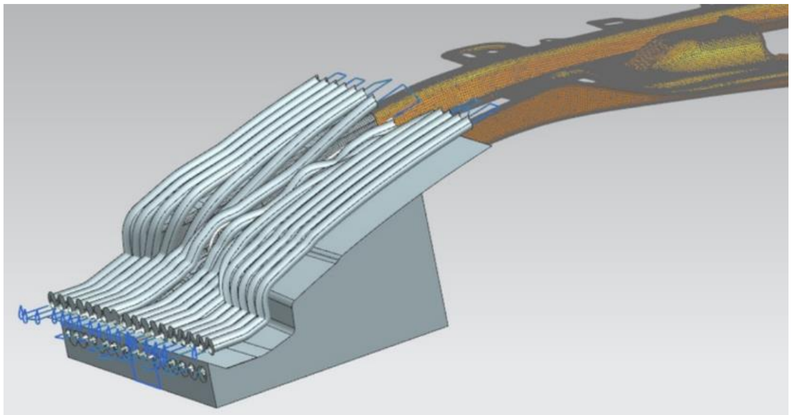

Fig 1.12 Adaptive cooling system design

3.2 Simulation analysis of redesigned refrigeration

3.2.1 Analysis of simulation 0

To compare the results, a simulation 0 has been defined. In this simulation, the analysed process parameters have been used without the optimization of the channels. In addition, some control nodes have been defined on the sheet to be able to compare the results depending on the simulation time.

In the following image fig 1.13 we can see the temperature of the sheet in second 1 of the simulation.

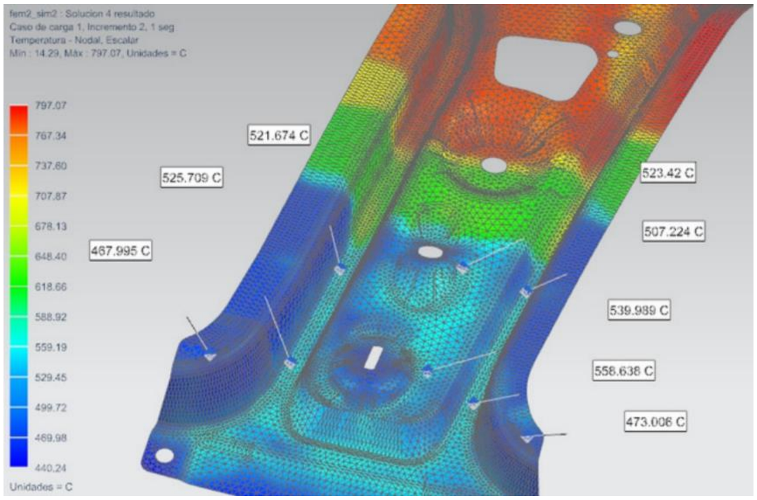

Fig 1.13 Sheet metal temperature in 1 sec

The sheet metal extraction temperature, defined at 200ºC in hot stamping processes, is achieved after 4.6 seconds of process simulation Fig 1.14.

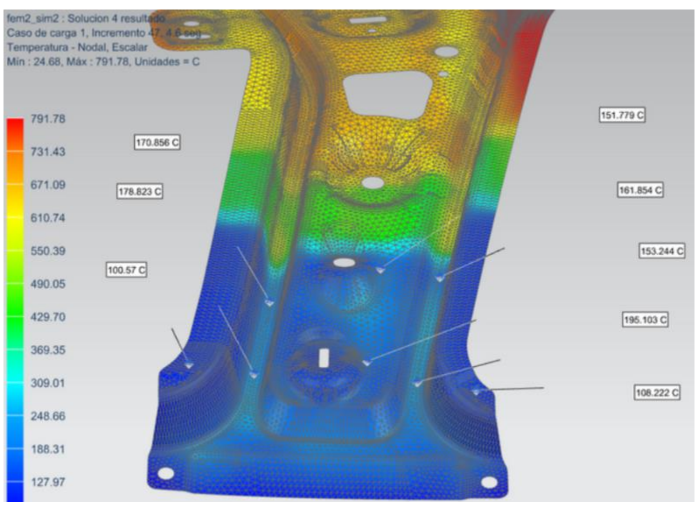

Fig 1.14 Sheet metal temperature in 4.6 sec

3.2.2 Analysis of the Redesign simulation

The redesign of the block has been defined, for the upper and lower block. The inverted drop geometry and the adaptive channels for the sheet metal have been defined. The simulation has been proposed with the same conditions used in simulation 0. The control nodes defined are the same, in order to standardize the temperature control in the sheet metal.

In the picture fig 1.15 we can see the temperature of the sheet in sec 1 of the simulation.

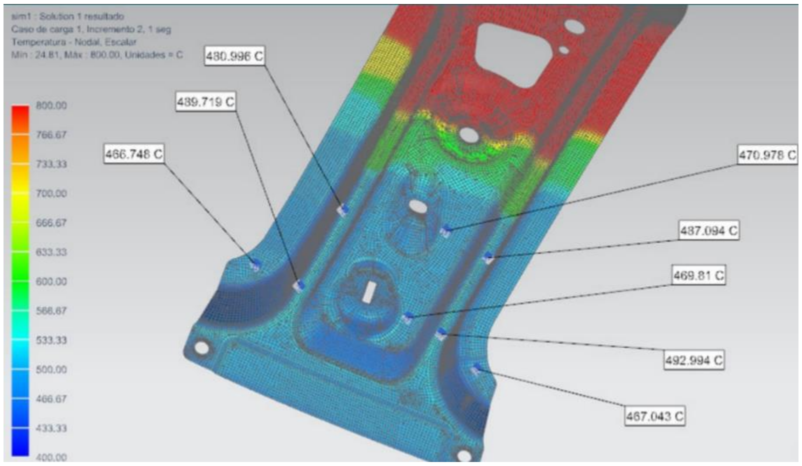

Fig 1.15 Sheet metal temperature in 1 sec

In the following image fig1.16 you can see that the sheet extraction temperature of 200ºC is obtained in sec 2.8 of the simulation.

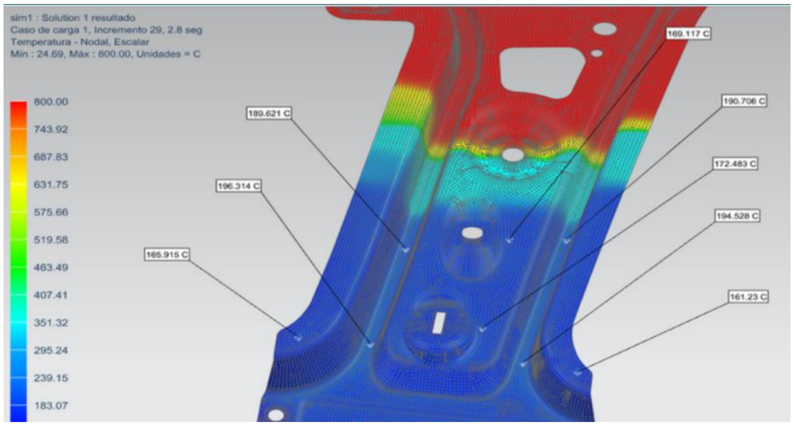

Fig 1.16 Sheet metal temperature in 2,8 sec

4. CONCLUSIONS

4.1 Economy assessment

With the results obtained in this analysis, it can be stated that the adaptive drop-shaped design optimizes the hot stamping process to the maximum. Comparing the results in Fig 1.14 and Fig 1.16 it can be observed that the result of ejection temperature fit in 200ºC, was obtained 1.8 seg earlier, in the redesigned stamp die block.

Simulation tests have been carried out by reducing the channel size and increasing the number of channels. We didn´t detect significant results compared to simulation 1.

All of this contributes to the cycle shortage growing and the piece-hour cost being reduced by production costs.

If we propose an economic study of the possible benefit in the manufacturing cost of the part under study, the following data can be provided:

Economic valuation reduction of hot stamping cycle time		
Type of Line	Medium Line (2 pilar B for cycle)	
Cycle total time	22	sec
Cycle time Furnace+Robot+Cooling	12	sec
Cooling cycle optimization	1.8	sec
Optimization % with respect to total cycle time	8.18	%
Annual production	200.000	Units/year
Hour Cost	950 €/h	
Line performance	70	%
Production hour	229.09091	Units/hour
Part process price	4.1468254	€/unit

Optimized hourly production	249.50495	Units/hour
Part process price	3.8075397	€/hour
Annual Cost Reduction	67857.143 €	

Fig 1.17 Cost analysis

If we look at the results in Fig 1.17, we can see an annual saving in production expenses of 67.857,143 euros. A significant saving in the economic situation we have nowadays.

4.2 Fabricability assessment

If we analyse the manufacturing of the blocks, we have to mention that additive manufacturing techniques represent an exaggerated cost in the manufacture of the block. For this reason, the aim is to dissect the block into parts that can be machined by conventional machining and parts that can be manufactured using SLM additive manufacturing.

If we analyse the cost of the SLM process, we can affirm that the cost of the C300 tool steel material amounts to €2349.84. Without taking into account the amortization, operation electrical energy, operating costs...

In addition to 3D printing, the stamp block should be mechanised and polish to obtain the superficial optimal quality.

For these reasons, we can affirm that the process savings are practically covered by manufacturing costs. All of this will be reduced by the development of new materials by new manufacturers and the appearance of new references in the metal powder market for SLM processes.

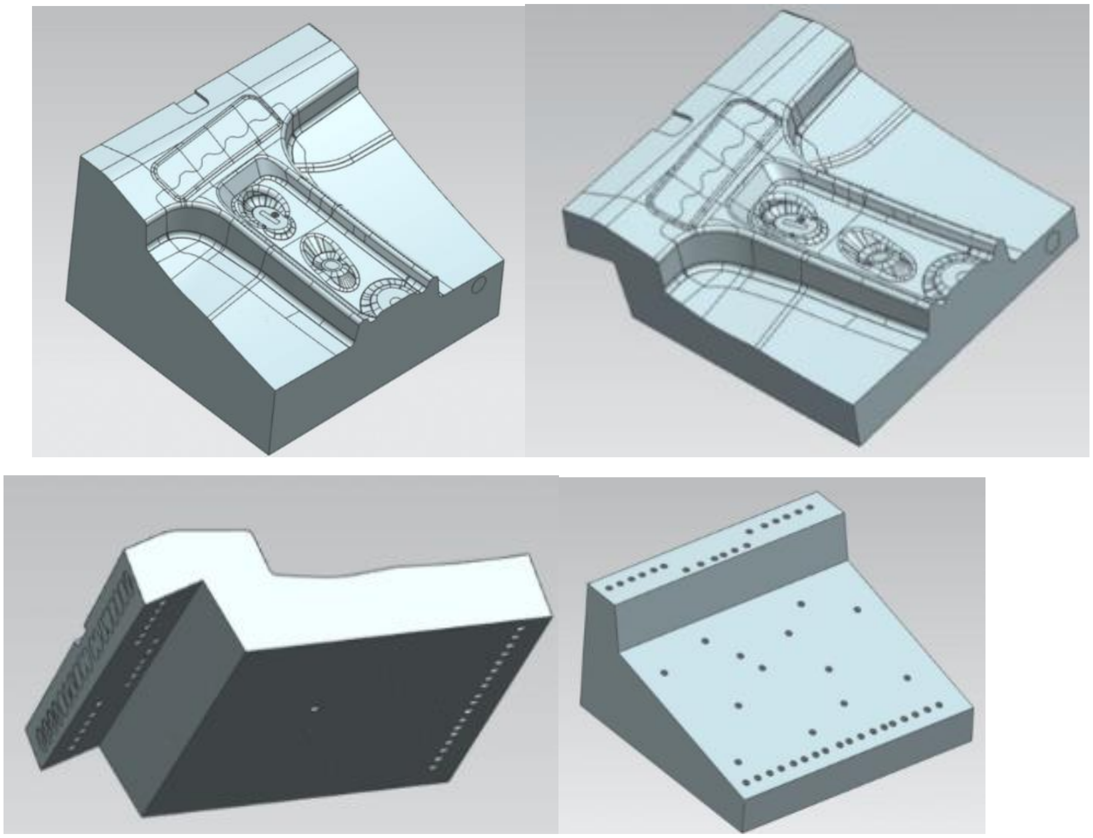

Fig 1.18 Hot Stamp Die Blocks Fabricability simplification

Research projects have been published on the additive manufacturing of hot stamping tools with adaptive channels. It is worth mentioning Study of the viability of manufacturing the cooling channels of hot stamping dies via Laser Metal Deposition project developed by the Bilbao School of Engineering EHU/UPV (Arrizubieta et al., 2019).

In this project the adaptive channels were manufactured using LMD. Due to the manufacturing process using Laser Metal Deposition, the drop shape was caused by the manufacturing process Fig 1.19, considered a side effect of the manufacturing process.

Fig 1.19 View of the channel closure manufactured using LMD (Leal et al., 2017).

Thanks to the simulations carried out, it has been detected that the drop shape, which was initially considered a manufacturing process failure, turns out to be the optimal shape for cooling.

4.3 General Conclusions

The main conclusion in this study is that inverted drop geometry produces optimal cooling in hot stamping processes.

Hot Stamping tools are usually made of highly tempered martensitic steels. Stamping operations often involve serious tensile and compressive stresses, as well as friction on the dies, which can be very aggressive on the contact surfaces that must be polished.

It should be mentioned that the materials used in additive manufacturing technologies do not meet the requirements for friction resistance that are present in hot stamping. In recent years, materials for tools have been developed, specifically high-weldability and good machinability martensitic materials.

Therefore, there is a wide field of research in the characterization of blocks manufactured through additive manufacturing. This includes new materials for stamping applications and the study of coating materials for blocks manufactured through additive manufacturing.

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